Influence of vertical temperature gradients on outdoor sound propagation in a narrow valley

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Introduction

Noise propagation in atmosphere is strongly influenced by vertical temperature gradients. Positive vertical gradients produce indeed a downward refraction of noise waves which cause an increase in the level of environmental noise.

The quantification of this increase in a specific case study by the collection of meteorological and noise data is the aim of the work.

This work follows the document presented by ARPA Valle d'Aosta at 34th *Convegno Nazionale Associazione Italiana di Acustica* – Florence, 2007 [1]. After this ARPA started a collaboration with Polytechnic of Turin for a master thesis work on this subject [2].

Case study

The data were collected in Aosta, a city of 35,000 inhabitants, situated in a standard alpine valley. In this city there are many noise sources, the most relevant being the motorway A5 and a steel factory. The motorway A5 is an important commercial route (Italy-France): every year almost 600,000 lorries pass through the Mont Blanc Tunnel. The steel factory is the most important industrial site of the Valle d'Aosta region (around 1000 employees).

The monitoring carried out by ARPA reveals the impact the steel factory has on noise production, and in particular by the foundry present in the factory. The main problem in the analysis was the total absence of information on the working cycles. To avoid as much as possible unrelated noise level changes, due to unknown source variability, it was necessary to enforce time restriction conditions, resulting by a statistical analysis on the data.

In an alpine valley, thermal inversion phenomenon occurs very frequently: every high atmospheric pressure situation produces positive vertical temperature gradients.

In winter, the occurrence of thermal inversion at night is equal to 50%.

To study this phenomenon data were collected on the following variables:

- Temperature
- Wind speed and direction
- Rainfall
- Noise

In 2006, 10 thermometers were installed on the slope located in the south of Aosta (facing North) to create a 1000 meters high thermal profile.

Wind and rainfall data were collected in one point only, so there is no profile for those data.

Noise data were collected in 6 different points in order to describe the best acoustic climate existing around Aosta.

Those data were collected in continuum in only one point whereas other measures were collected weekly or monthly.

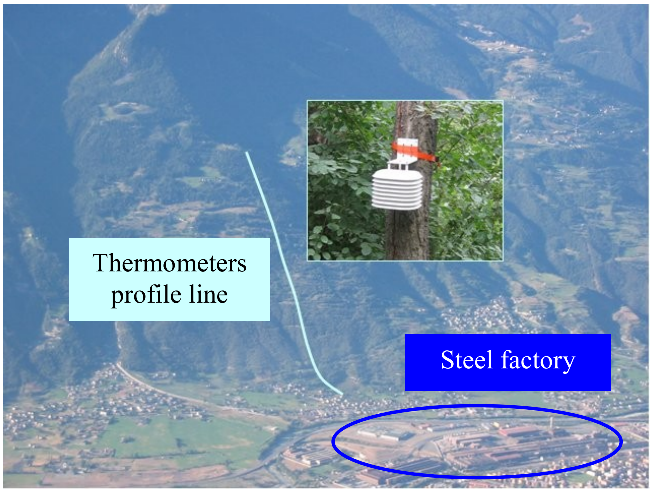


Figure 1 Thermal profile position

Position of sound-level meters

Sound-level meters were placed North and South by the main noise source. 3 Sound-level meters were placed at the source altitude (550 m a.s.l.) and 3 higher:

Noise meter	Altitude [m a.s.l.]	Data % *
South hillside	780	67
Bottom of the valley	575	11
City 1	580	7
North hillside	725	6
City 2	580	5
Highest point	1090	2

* "Data %" means amount of noise data compared to meteorological data.

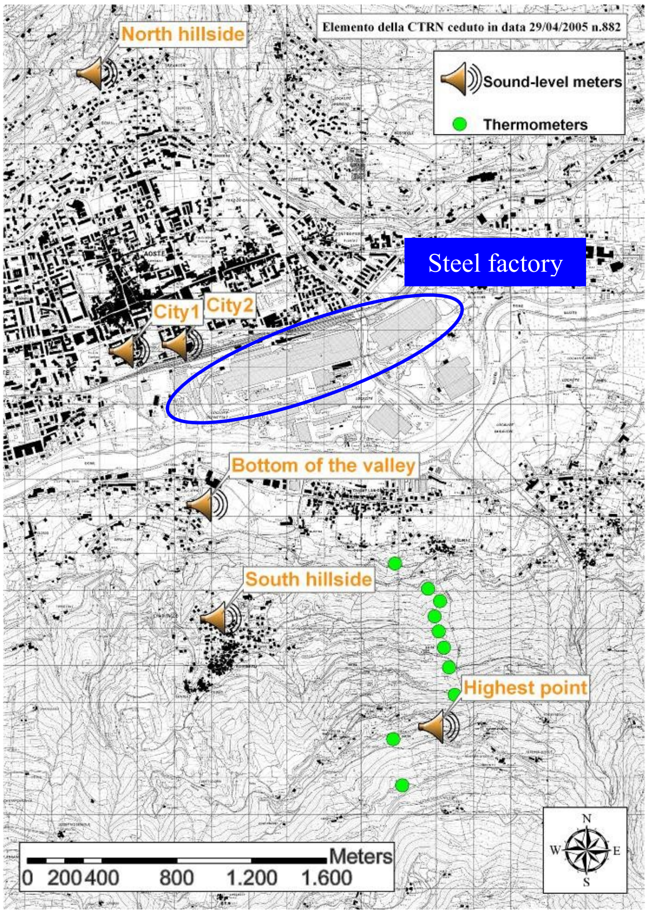


Figure 2 Sound-level meters positions

Thermal profile data analysis method

The thermal profile data were processed following the reference method developed in the European Harmonoise project [3].

The analysis method is founded on the equation:

$$c_{ad} = \sqrt{kRT(z)} \approx \qquad [\text{m/s}] \qquad (1)$$

$$\approx c_0 + \frac{1}{2}\frac{kR}{c_0}\left(T(z) - T_0\right) \approx$$

$$\approx c_0 + a_c \ln\left(1 + \frac{z}{z_0}\right) + b_c z$$

Where: $T(z)$ is air temperature on the profile at altitude z;

a_c and b_c describe profile bending and slope.

Each thermal profile was described with the 2 coefficients a_c and b_c to simplify the correlation between temperature gradients and noise levels.

Meteorological classes are based on those coefficients; the classification research is an attempt at setting up the most representative system regarding each different atmospheric condition. This was the most relevant part of the work.

After the thermal profile conditions classification was done, it was possible to create a correlation between meteorological data and noise data.

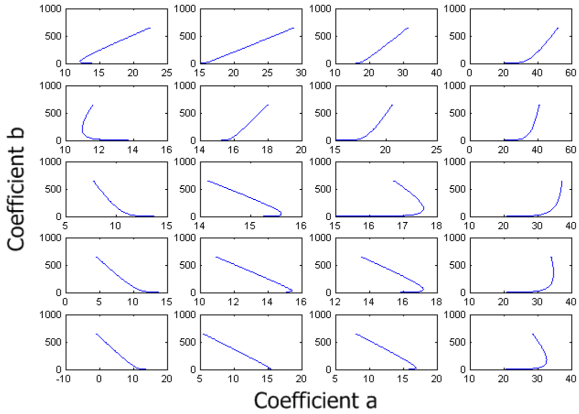


Figure 3 Thermal profile classification

Conditions

The loss of information regarding the noise source was the main problem to solve during the analysis. The research of the most stable environmental noise condition was therefore necessary to ascertain that the increases/decreases of noise levels were exclusively due to temperature gradients.

Only situations satisfying those conditions were considered:

- Months: November - March
- Days: Tuesday- Friday
- Hours: 8:00 pm - 7:00 am
- Wind speed < 1 [m/s]
- Precipitation = 0 [mm]

Considering only winter period means concentrating all the analysis when thermal inversion occurs very frequently. Only week days were considered. The more stable acoustic climate during the night explains the choice of making the analysis at that moment only. Wind and rain badly influence the noise propagation so were excluded from the analysis. More than this some analysis on meteorological data showed that the presence of rain or wind excludes thermal inversion situations.

L95 was chosen from noise mapping in order to assess the variations on background noise only and to avoid impulsive noise disturbance.

Analysis Periods

Some analysis on noise data showed an important time dependent noise level variation in some sound-level meters. This variation was recorded approximately during half of the analysis period. A research on documents delivered by the most important noise source (steelfactory) showed that in the end of 2008 noise sanitation works were made to reduce noise emissions. For this reason it was necessary to separate the analysis period in two independent parts.

Statistics restrictions

To increase the meaning of noise level changes in different atmospheric conditions, statistics and numeric restrictions were tried, by imposing a maximum standard deviation and a minimum measures number.

Restrictions:

- Measures number > 10
- Standard deviation < 3 dBA

These restrictions were useful in points with a huge number of measures. The lack of noise data resulting from uncontinuous noise mapping made the results meaningless in different points. This is mostly caused by too few data outputs, especially adding up this condition with the previous ones.

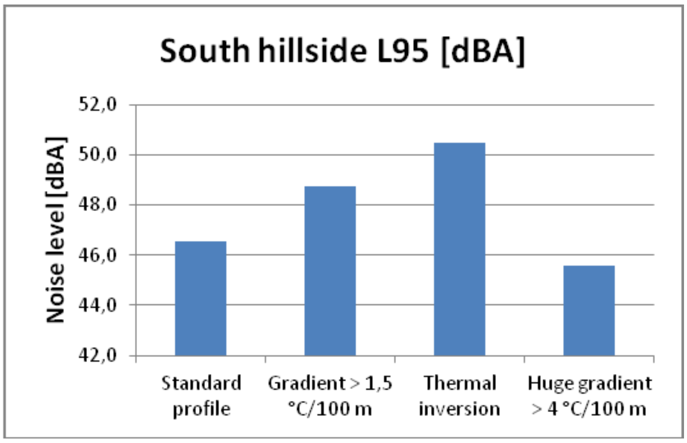
Results

All the analysis were made using a discrete method referring to different temperature profile classes. To make the reading of results easier, the levels are shown as histograms, grouping similar meteorological classes.

The results related to "Highest point" are not presented because they are not reliable. This is caused by the insufficient number of data.

South hillside

Results in this point are the most important. This is due to the large number of measures collected here in continuous. This allowed to group in different meteorological classes many noise levels, making results more reliable.



These results are referred to the first period 2006-2008.

The group "Gradient > 1,5 °C/100 [m]" is referred to situations in which the thermal inversion occurs only in the lower part of the profile.

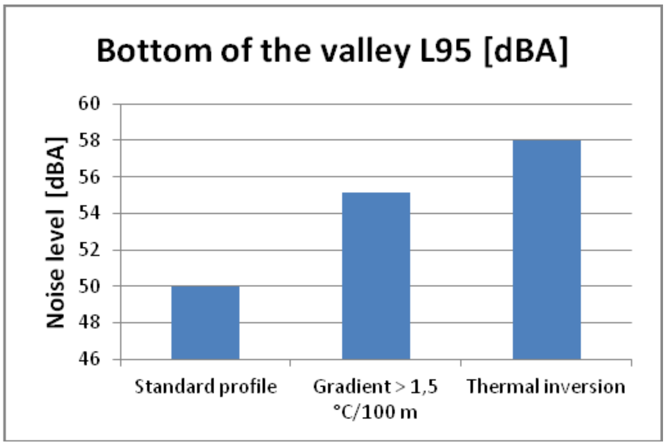
In the first three classes the direct correlation between thermal inversion and noise levels is clearly visible and it is evident that an increase of positive thermal gradients produces an increase in noise levels. These increases are quantifiable in 2 – 4 dB.

The last bar shows situations in which a huge positive thermal gradient hides the receptor from noise emissions. In these situations the important downward refraction does not let the noise waves reach the measuring point. The sound-level meter is placed 200 meters above the noise source, which is sufficient to place the receptor in a shadow zone, the fourth condition.

In this point the difference between Leq and L95 is around 3 dB (in absence of wind, rain and at night).

Bottom of the valley

Data number available in this point is lower than in the previous one, around 1/6 compared to South hillside point. This is the reason for a major uncertainty in the results.

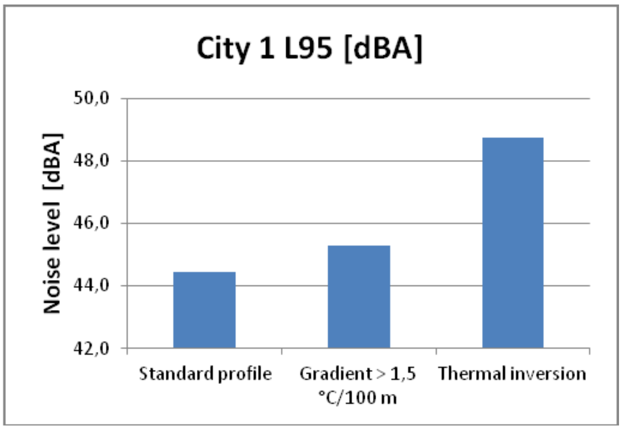


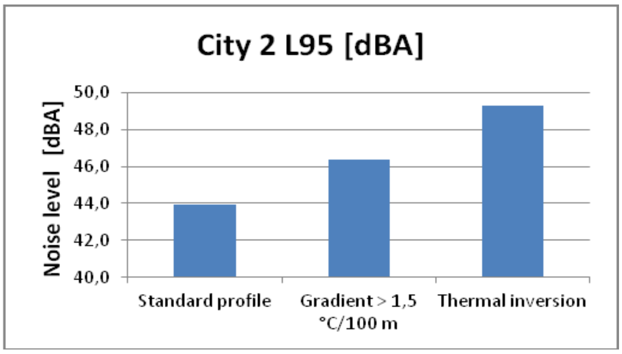
Firstly it is evident that the general increase in noise levels, compared to the "South hillside" point is caused by the proximity of the main noise source. Also the noise levels increase in different conditions is more evident (5 and 8 dB). Here the sound-level meter is placed at the same altitude of the source so the condition with only the lower part of the profile in thermal inversion wasn't considered. This assumption was confirmed by the results of the analysis. In this point the biggest noise level increases were recorded; this is arguably due to the vicinity of the noise source (~ 1 km).

It is worth noticing how law limits are respected in standard atmospheric conditions while these limits could be disrupted when thermal inversion occurs (in this area the law limit during the night is 50 dBA – III Class of the acoustic classification). This result should be considered during noise mapping and environmental noise description.

Here the difference between L_{eq} and L95 is around 4 dB, close to the previous one, but there the general noise was clearly reduced.

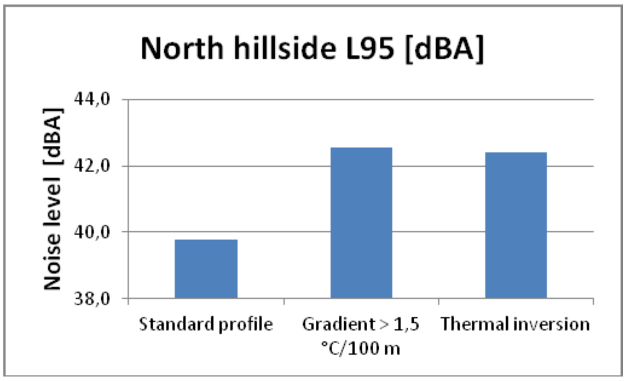
City 1 and City 2





The results obtained in these two points show the reliability of the analysis made. The vicinity of the two sound-level meters made possible to compare the results obtained. It is possible to observe how noise level changes are very similar even if the measuring periods aren't the same. It is possible to observe 3 and 5 dB increases, it is also interesting to note lower noise in general, recorded at the "Bottom of the valley" point. This is explained by the position of the points, despite the distance being around 1 km. In this case the buildings situated between the source and the receivers act as an acoustic barrier. This also explains the noticeable amount of noise levels due to the increase of positive thermal gradients; this is caused by the major downward refraction at higher levels in the atmostphere which let more acustic waves overpass the buildings.The difference between Leq and L95 here is around 6 dBA. The urban position of these receptors explains the amount mentioned in previous noise meters and it makes the choice of the L95 on the analysis more reliable.

North hillside



This point is the furthest from the noise source: it is evident a general decrease in the noise levels. This observation confirms that the main noise sources identified were correct. However, the effects of positive thermal gradients are evident in this sound-level meter too. The amount is quantified in 3 dB. It is worth noticing the amount is almost the same as the one recorded in "South hillside" point. This is important because the receptors are placed at the same altitude but on the other side of the valley. The results are therefore comparable.

Conclusions

The results presented show how positive thermal gradients have a significant impact on environmental noise propagation, producing an important level increase. Since this meteorological phenomenon occurs very frequently in alpine valleys, it should be more considered in acoustic mapping and in numerical modeling. Generally speaking this is important to make accurate noise predictions where particular meteorological conditions occur, considering negative factors like the ones presented here. These increases are relevant and therefore they need to be taken into account in this particular situation.

Finally it is important to remember that this analysis is based on empirical data. Every analysis made on environmental themes are naturally subjected to a certain level of incertitude. In this case the incertitude problem is reduced by the long-term period of the analysis which enabled a significant collection of data.

References

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[3] Defrance J., Salomons E., Noordhoek I., Heimann D., Plovsing B., Watts G., Jonasson H., Zhang X., Premat E., Schmich I., Aballea F., Baulac M., Roo de F., 2007: *Outdoor sound propagation reference model developed in the European Harmonoise project*. Acta Acustica, 93, 213-227.